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# USACE Asset Management Workshop

## An Overview of Engineering Risk and Reliability Methods for USACE Studies

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# Overview of Engineering Risk & Reliability

## Outline of Presentation

1. What is Risk? What is Reliability? Why is it Used?
2. Engineering Reliability Modeling Characteristics
3. Acceptable Methods for Engineering Reliability
4. Basic Features of Reliability Modeling and Analysis
5. Consequence Event Trees
6. New Engineering Reliability Guidance
7. New USACE DX for Risk and Reliability

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# Five Required Elements of Risk

1. Likelihood – future uncertainty of an event
2. Outcome – link paired with likelihood in risk profile
3. Significance – amount of gain/loss for a particular outcome
4. Casual Scenario – causes of an event & subsequent outcome
5. Population – important aspect for life safety issues

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# Risk Assessment/Management

Risk Assessment Determines:

- ✓ Likelihood
- ✓ Outcome
- ✓ Causal Scenario
- ✓ Population

Risk Management Determines:

- ✓ Significance
- ✓ Course of Risk Aversion/Mitigation
- ✓ Risk vs. Cost Tradeoffs

# Reliability Analysis

Reliability – probability that a system will perform its intended function for a specific period of time under a given set of conditions

$$\boxed{R = 1 - P_f}$$

Reliability is the probability that unsatisfactory performance or failure will not occur

# Reliability Analysis

- Probability of Failure ($P_f$) – easily defined for recurring events and replicate components (such as light bulbs, etc…)

- Probability of Unsatisfactory Performance (PUP)
  - ✓ Tough to define for non-recurring events
  - ✓ Typically, USACE structural elements fall into this category for a variety or reasons
  - ✓ Examples (sliding of gravity structures, fatigue cracking of gates, etc…)
  - ✓ Many times can be classified as an "economic failure" when consequences are significant

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# Relationship Between Risk & Reliability

Costs * PUP = Consequences → Risk

Annual probabilities computed from an engineering reliability model

Cost Examples for USACE Projects
Emergency Repairs
Delay Times for Users
Increased O & M Costs and/or Frequency
Damages to Users
Benefits Foregone

→ Event Tree

# Reliability Modeling Basics

Probabilistic Modeling the Current and Future Condition of Structures/Components for Decision Making

Historical Information About Component

- Previous Maintenance and Failures
- Accounts for Historical Patterns and Future Condition

Realizes Probabilistic Nature of Engineering Analysis

Develop Probabilities of Unsatisfactory Performance for Components Over Period of Study

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# Reliability Analysis –Why is It Used?

- Analysis Tool Used by USACE to Prioritize Investments
  - Major Rehabilitation Studies
  - Dam Safety Portfolio Risk Assessment
- Recognizes and Captures Uncertainty in Analyses
  - Engineering Uncertainties – Loads, Material Properties, Corrosion, Fatigue, Stress Concentration Factors, Etc…
  - Economic Uncertainties – Traffic Forecasts, Rate Savings
- Shows Economic Justification and Risks Associated with Multiple Future Investment Alternatives
  - Fix-as-Fails Maintenance, Advance Maintenance, Major Rehab
- Allows a Method to Rank Projects Based Upon Risks Associated with Life Safety and Economics

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# Reliability Modeling Characteristics

## Investment Tool for Decision Making

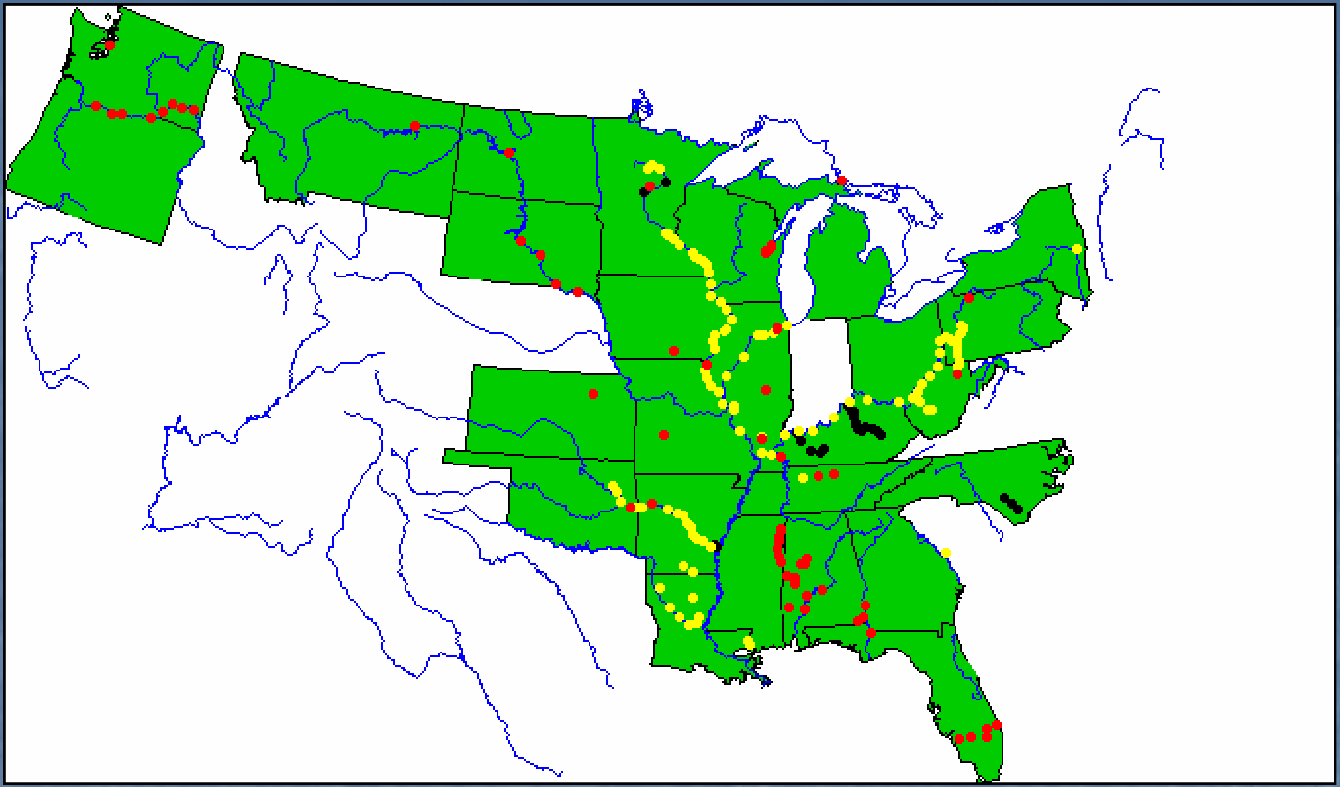
- Measures the risk (life safety/$$$ damages) associated with performance of a component and/or system of components
- Reliability model itself is just one piece of the overall analysis. Integrates with consequence analysis through event trees.
- For an overall project, all critical components are analyzed to determine their performance through the study period (50 years for most USACE studies)

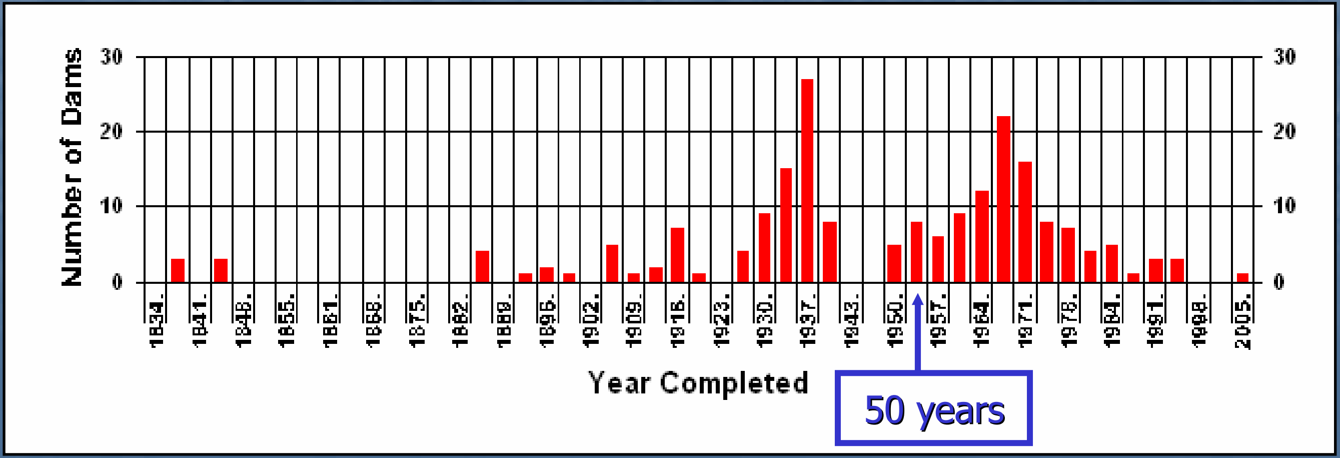
# Aging Infrastructure Prioritization

*Navigation Projects*
*Flood Control Projects*

*Where are our biggest risks to life safety?*
*What are greatest needs for navigation system?*

# USACE Navigation Projects – Aging Infrastructure






VITAL STATISTICS

238 lock chambers

Average age = 58 years

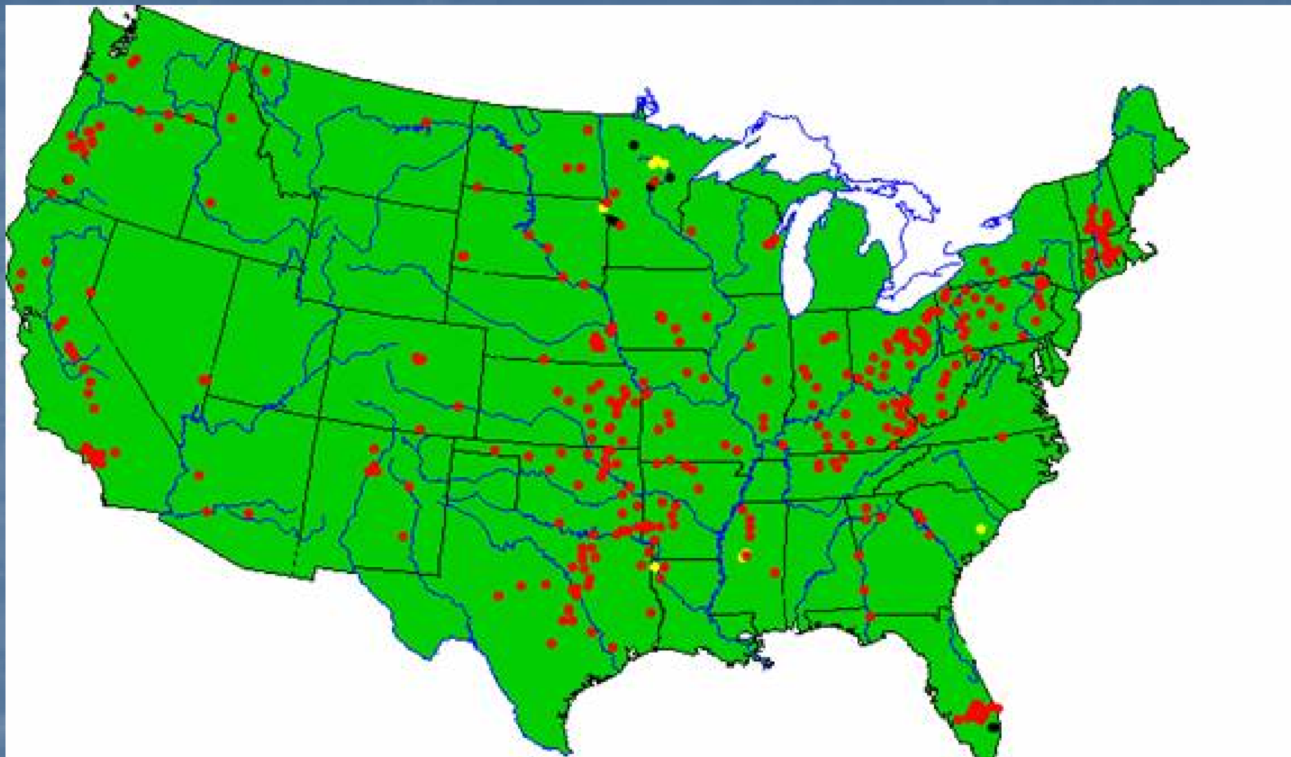
Median age = 51 years

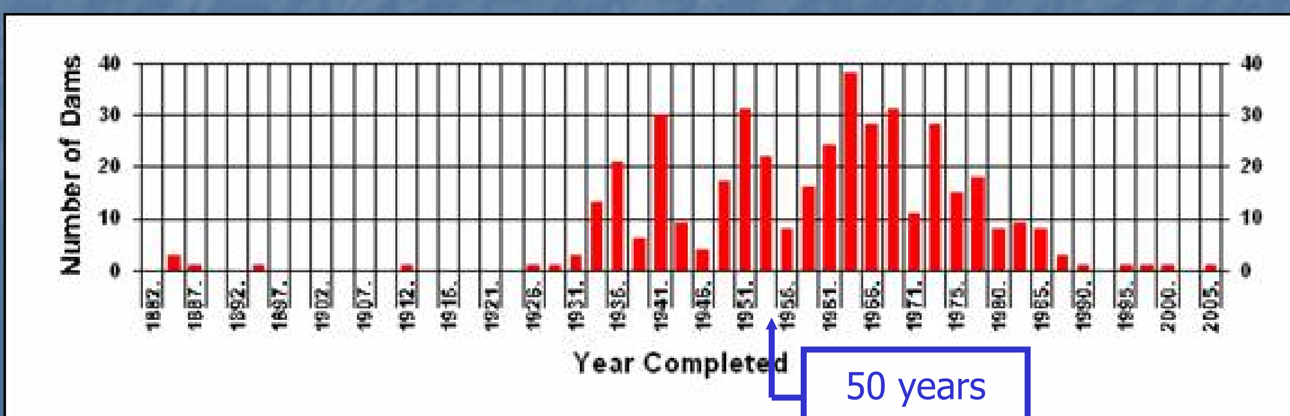
46% over 50 years

58% in next 10 years

- Low hazard project
- Significant hazard
- High hazard project

# USACE Flood Control Projects – Aging Infrastructure






VITAL STATISTICS

400 flood control dams

Average age = 46 years

Median age = 44 years

42% over 50 years

67% in next 10 years

- Low hazard project
- Significant hazard
- High hazard project

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# Acceptable Methods for Reliability Analysis

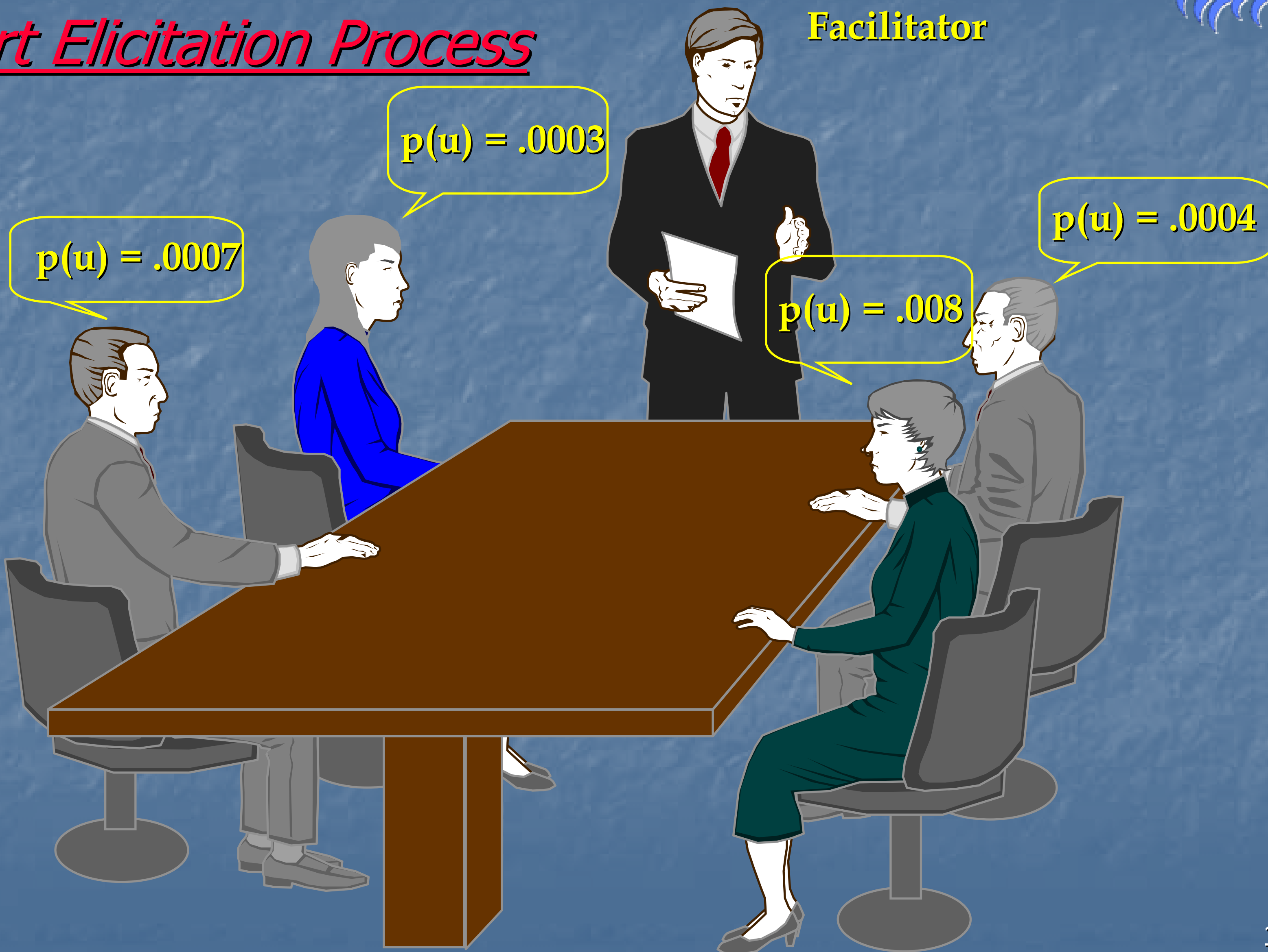
# Engineering Reliability Analysis

## Currently Four Acceptable Methods in Guidance

- Reliability Index Method (Probabilistic Method)
  - Uses Beta values to determine point estimates of reliability
  - Not applicable for time dependent situations, issues w/ multiple random variables in the analysis
  - Originally used when software and computational packages were limited
- Hazard Functions Analysis (Probabilistic Method)
  - Preferred method using analytical models with Monte Carlo simulation
  - Handles time dependency and multiple, correlated random variables
  - State-of-the-art method used on ORMSS, Markland Rehab Study
- Historical Frequency of Occurrence / Survivorship Curves
  - Best method but database of failures not available for civil works structures
  - Applicable for other components, such as motors
- Expert Elicitation Process
  - Uses judgment from a panel of experts to establish failure probabilities
  - Only used to supplement analytical methods

Note: On-going reliability guidance should supercede this guidance over next 2-3 years with an EC on USACE Infrastructure Engineering Reliability Analyses

# Expert Elicitation Process



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# Expert Elicitation Process

Solicitation of "experts" to assist in determining probabilities of unsatisfactory performance or rates of occurrence

Formal process with a facilitator, panel of experts, observers, and training period to remove bias and dominance

Should be used to supplement analytical reliability models as part of an overall risk assessment for a project

Recent project studies using expert elicitation

- Nashville District (Chickamauga Lock Replacement Study)
- Pittsburgh District (Ohio River Mainstem Study – Emsworth Lock)
- Louisville District (Mill Creek Flood Protection Project)
- Vicksburg District (Lindy C. Boggs Lock Wall Evaluation)

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# Historical Frequency Method

- Use of known historical information for records at site to estimate the failure rates of various components

- Excellent method, but usually USACE projects do not have enough historical failure performance to develop future probabilities

- Example: if you had 5 hydraulic pumps in standby mode and each ran for 2000 hours and 3 failed during standby mode, the failure rate would be as follows:

  Total standby hours = 5 * 2000 hours = 10,000 hours
  
  Failure rate (standby mode) = 3 / 10,000 = 0.0003 failures/hour

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GREAT LAKES & OHIO RIVER DIVISION

# Manufacturer Survivorship Curves

- Excellent method that is very similar in nature to historical frequency method
- There are enough failures to develop survivorship curves for different components (light bulbs are an excellent example). These are usually provided by the manufacturer for items such as pumps, motors, etc…
- Same as historical frequency, USACE components typically do not have enough "failure" events to establish survivorship curves with the exception of some components at hydropower facilities (generators, etc…)

# Probabilistic Methods

Reliability Models Are:

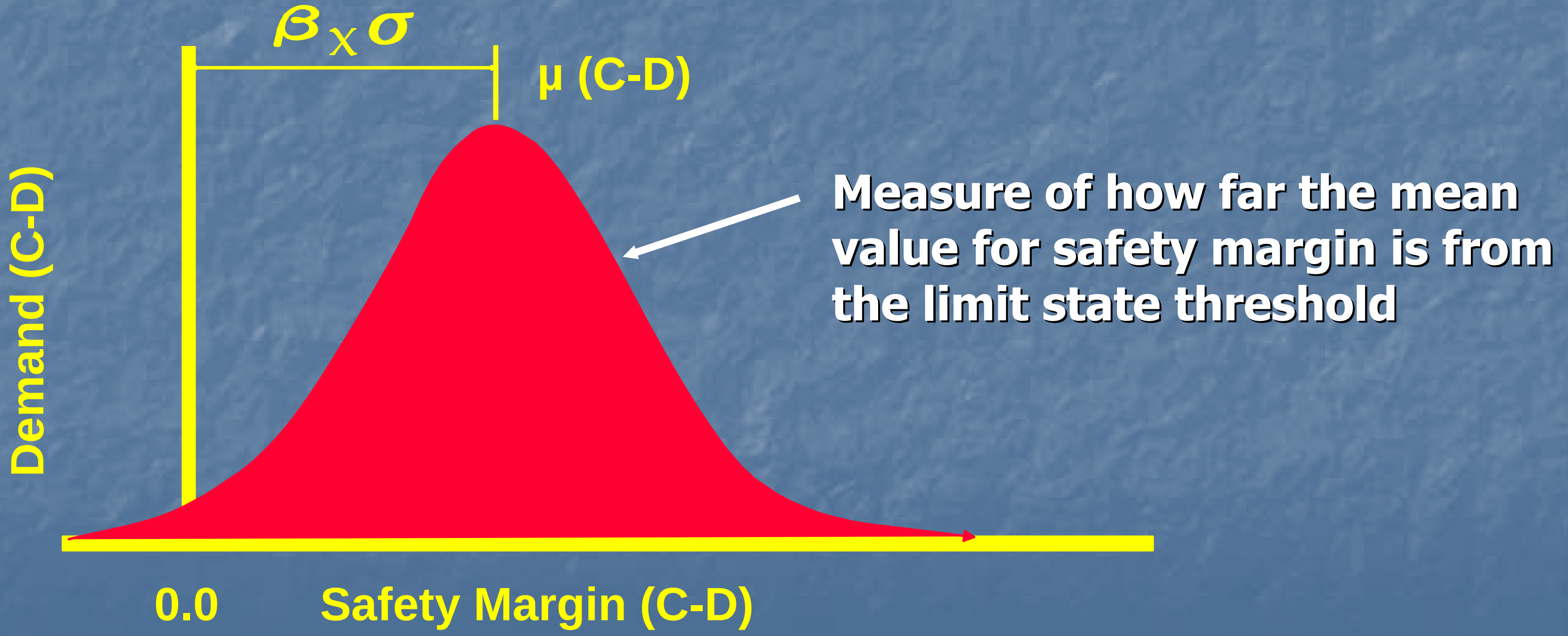
- ✓ defined by random variables and their underlying distributions
- ✓ based upon limit states (analytical equations) similar to those used in design or analysis of a component
- ✓ based upon capacity/demand or safety factor relationships

Two Probabilistic Methods of Developing Reliability Models are Currently in Use within USACE:

- ✓ Reliability Index ($\beta$ Method)
- ✓ Hazard Function Analysis

# Reliability Index (β Method)

- Utilizes Taylor Series Finite Difference
  - 1st order expansion about the mean value
  - Linear approximation of second moment
  - Uses a factor of safety approach
  - Easy to implement in spread sheets



# Reliability Index (β Method)

Major Shortcomings Associated with β Method:

- ✓ Instantaneous that represents "snapshot" in time and is not applicable for time dependent structures whose conditions degrade with time
- ✓ Only applicable for a few distribution types and not efficient when there are many random variables and when some are correlated with one another
- ✓ Many times errors made on underlying distributions used to calculate β
- ✓ Originally used when computation power and commercial software was not adequate for simulation model development

# Hazard Function Analysis

- Preferred Method of Computing Probabilities of Failure
  - ✓ Started with insurance actuaries in England in late 1800's
  - ✓ Brought into engineering field with aerospace industry in 1950's
  - ✓ Accounts for the knowledge of the past history of component
- Computes the Rate of Change at Which the Probability Changes Over a Selected Time Step (Usually Annually)
  - ✓ Not a "snapshot" in time, it is truly cumulative
  - ✓ Uses Monte Carlo simulation techniques to calculate the true probability of failure (or PUP)
  - ✓ Can easily be developed for time dependent and non-time dependent models from deterministic engineering design procedures

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# Hazard Function Analysis

**Definition:**

The hazard function, h(t), is the conditional probability of unsatisfactory performance of a structure or component at time t given that it has survived up to the selected time

$$h(t) = f(t) / R(t)$$

where: $f(t)$ = pdf at time $t + \Delta t$

$R(t)$ = cumulative reliability up to time *t*

When using Monte Carlo simulation methods it can be simplified to the following formula:

$$h(t) = \text{\# of failures } (t_i) \text{ / \# of survivors } (t_{i-1})$$

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# Summary of Probabilistic Methods

For Components Whose Reliability will not Degrade with Time (Non-Time Dependent Reliability Analysis):

- ✓ Linear limit states with normal or lognormal input distribution types – Reliability Index (β Method) or Monte Carlo simulation methodology is appropriate
- ✓ Non-linear limit states – Monte Carlo simulation methodology
- ✓ Typical USACE examples: gravity structures w/o changing loads

For Components Whose Reliability Degrades with Time (Time Dependent Reliability Analysis):

- ✓ Hazard function analysis using Monte Carlo simulation methodology
- ✓ Typical examples: hydraulic steel structures, deteriorating concrete, anchored walls, mechanical/electrical equipment, etc…

# Basic Features of Reliability Analysis

# Basic Parts to a Reliability Analysis

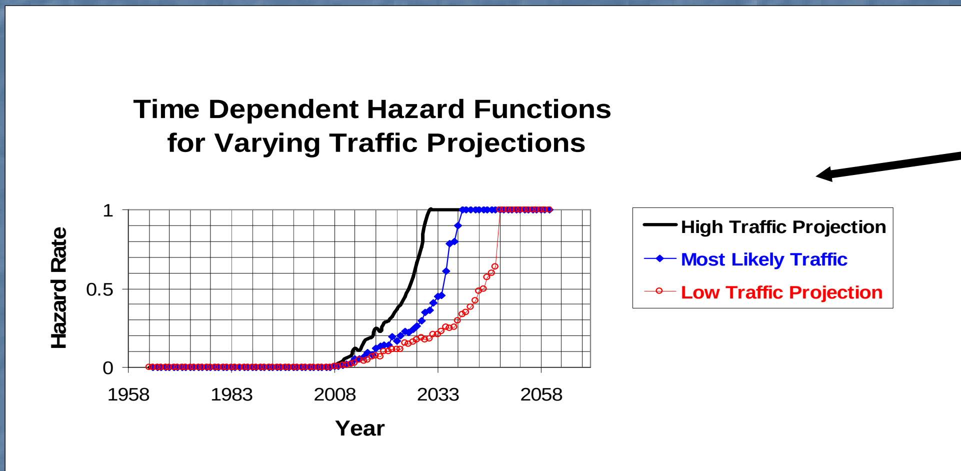
- Limit State which is the failure mechanism that is being investigated such as stability of gravity structures or fatigue analysis for steel structures
- Random Variables which are input values for the analysis that are allowed to vary according to some distribution.  Example might be yield strength of steel, corrosion rate...
- Constants are input values to model that hold the same value for each iteration such as unit weight of water, etc.
- Counter which tabulates iterations that reach the limit state (or fail) versus those that never fail.  Used to track the number of failures and survivors for each time period analyzed.
- Event Tree which is developed to show randomness associated with different levels of repair given a failure. This is developed separate of the reliability model and is provided to depict the consequences associated with unsatisfactory performance.

# Required Info for Consequence Analysis

- Annual Hazard Rate (Time Dependent Components)
- Single PUP (Non-Time Dependent Components)
- Consequence Event Tree for Each Component/Scenario
  - Only evaluate significant consequences
  - Various level of repairs
  - Cost to repair & other damages (time out of service, etc…)
- Updated Hazard Rate for Repaired Components
- Consequences Associated with Schedule Repair Prior to Failure to Compare vs. Fix-As-Fails Scenario

# Engineering Requirements

## Reliability Modeling – Outputs and Integration with Economics




Time dependent probabilities of failure for various alternatives through study period

| Component | Annual Hazard Rate | Level of Repair | Closure Time | Repair Cost | Effect on Overall Component Reliability |
|---|---|---|---|---|---|
| | Annual Reliability Value (1 - Annual Hazard Rate) | | | | |
| Horizontally-framed Miter Gate | | New Gate 5% | 365 days in year 1 | $13,150,000 | Assume R = 1.0 for All Future Years |
| | | | 90 days in year 2 | $3,150,000 | |
| | Annual Hazard Rate | Major Repair 35% | 45 days in year 1 | $1,575,000 | Move Back 5 Years |
| | | | 45 days in year 2 | $1,575,000 | |
| | | Temporary Repair 60% | 45 days in year 1 | $3,575,000 | Assume R = 1.0 for All Future Years |
| | | Replace 1st Set of Gates | 45 days in year 2 | $3,575,000 | |
| | | Replace 2nd Set of Gates | 30 days in year 3 | $5,050,000 | |

SCHEDULED REPLACEMENT BEFORE FAILURE INFORMATION
Year 1 -- 30 Days of Closure @ $5,050,00 Year 2 -- 30 Days of Closure @ $5,050,000
Future Reliability Will Equal 1.0 Throughout Remainder of Study Period

Consequence event tree given the limit state is exceeded in the reliability analysis

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# Consequence Event Trees

# Consequence Event Trees

## *Background Information*

- ✓ Mechanism That Interfaces Engineering and Consequences
- ✓ Provides Consequences (Repair Cost, Service Disruption Time, Etc.) Associated with Unsatisfactory Performance of Component
- ✓ Critical to Overall Consequence Evaluation for Loss of Life and Economic Damages
- ✓ Information Developed Consistent with Reliability Limit State Modeling
- ✓ Developed for Individual Maintenance Strategies

# Consequence Event Tree
## Basic Parts

EVENT FREQUENCY -- Determined for each load case being evaluated

↓

RELIABILITY MODEL INPUT -- Given the event occurs, what is the probability of unsatisfactory performance?

↓

RANGE OF FAILURE -- Given limit state being modeled, what are the possible levels of failure given that it occurs?

↓

CONSEQUENCES OF FAILURE & REQUIRED REPAIR -- For each level of failure, what are the expected consequences (loss of life, $$$ damages)?

↓

EFFECT ON FUTURE RELIABILITY -- Following the repair, what is the improved reliability for future operations?

# Consequence Event Trees

## *Example Format*

| Branch 1 | Branch 2 | Branch 3 | Branch 4 |
|---|---|---|---|
| Load Case #1 % Time | (1-PUP #1) % | | |
| | PUP #1 % | Repair Level #1 % Consequence #1 | Reliability Upgrade Level #1 |
| | | Repair Level #2 % Consequence #2 | Reliability Upgrade Level #2 |
| Load Case #2 %Time | (1-PUP #2) % | | |
| | PUP #2 % | Repair Level #3 % Consequence #3 | Reliability Upgrade Level #3 |
| | | Repair Level #4 % Consequence #4 | Reliability Upgrade Level #4 |

Scheduled Repair/Replacement – Cost and Service Disruption Time

# Time Dependent Component

## Example Event Tree – Culvert Valves

| Component | Hazard Rate | Damage/Level of Repair | | Repair Cost | Chamber Closure | Future Reliability |
|---|---|---|---|---|---|---|
| Main Chamber Horiz.-Framed Culvert Valve | Annual Hazard Rate (AHR) | Catastrophic Failure Chamber Closed<br>Fabricate and Install 4 New Culvert Valves | 1% | $6,325,000<br>Split Over 2 Years | Closed 15 days in year of failure<br>90 days half-speed following year | R = 1.0 for All Future Years |
| | | Temporary Repair to Open Chamber<br>Fabricate and Install 2 New Culvert Valves | 49% | $5,000,000<br>Split Over 2 Years | Closed 10 days in year of failure<br>90 days half-speed following year | Move Back 20 Years |
| | | Major Damage<br>Major Repairs to Valves | 50% | $2,100,000 | Closed 5 days in year of failure | Move Back 5 Years |
| | 1- (AHR) | | | | | |

Scheduled Replacement of Culvert Valves for Main Chamber
Cost = 4*(400,000) + 90*(35,000) = **$4,750,000**
No Chamber Closure But **90 Days of Half-Speed Operation**

# Consequence Event Trees

## *Review of Key Points*

- ✓ Links Reliability Analysis to Consequence Evaluation Through Multiple Alternative Scenarios
- ✓ Consequences Consistent with Limit State Being Modeled in Reliability Analysis
- ✓ Significant Limit States/Consequences Effect Evaluation
- ✓ Expert Elicitation is a Good Means to Obtain Event Tree Values when Analytical Methods or Historical Performance is not Available

# Planning Requirements for Major Rehab

## Multi-Scenario Planning Options – Establishing the WOPC

- Key – establish the base condition
- Base condition should be calibrated to current field conditions
- Deterioration modeling without reliability upgrade repairs
  - What is future cost to keep project serviceable? What is future reliability?
- Advance maintenance repair scenarios
  - Short-term repair to temporarily upgrade reliability
  - What is the cost of repair? Service disruption time? Upgraded reliability?
  - Compare to the baseline plan
- Plan with the Highest Net Benefits Determines Optimized WOPC

## Developing the With Project Condition

- Replacement or long-term repair that provides substantial increase in reliability for the long-term performance of the structure
- Repair/replacement must meet Major Rehab cost and time thresholds
- Compared to optimized WOPC to determine if it is economically justified

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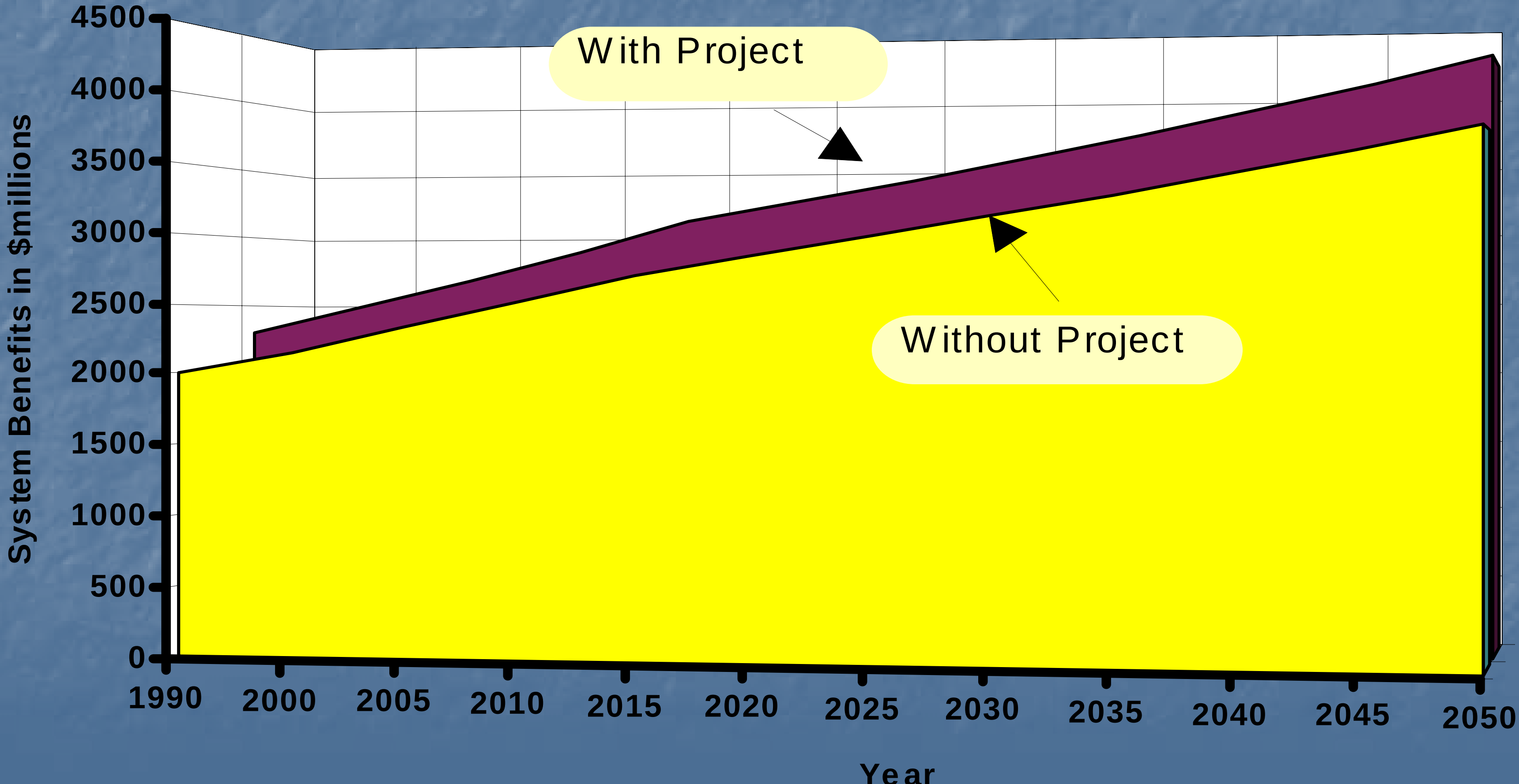
# Economic Analysis

## Incremental Benefits w/o Reliability-Based Consequences



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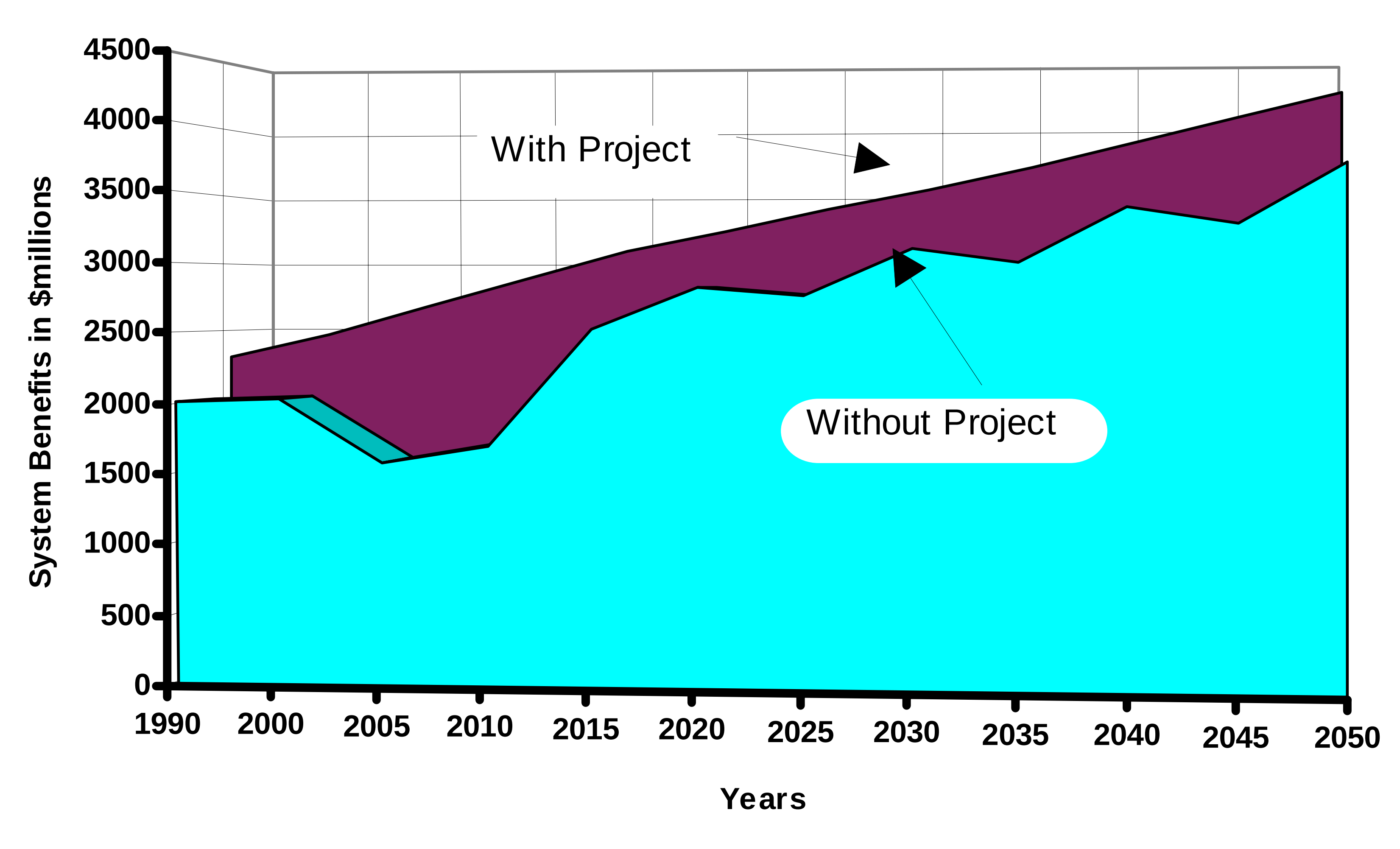
# Economic Analysis

## Incremental Benefits with Reliability-Based Consequences



# New Engineering Circular

## Engineering Reliability Guidance for Existing USACE Civil Works Infrastructure

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# New Engineering Reliability Guidance

## General Background

- Updating engineering reliability guidance sorely needed
- No systematic guidance that addresses development of other critical pieces of analysis such as event trees and integration within engineering guidance
- Currently, major rehab guidance document (EP 1130-2-500) is the general reliability guidance that has been used, but it is very old and has some outdated information
- Major rehab guidance will reference the EC document as the "source to use" for developing engineering reliability analysis

# New Engineering Reliability Guidance

## Structural Guidance

Currently, there is no structural reliability guidance since previous documents have been rescinded

Previous structural guidance has been rescinded due to more accurate, analytically correct techniques (Monte Carlo simulation) available with commercial software and PC speed

Rescinded structural guidance

- ETL 1110-2-321 "Reliability Assessment of Navigation Structures and Stability of Existing Gravity Structures"
- ETL 1110-2-354 "Reliability of Pile-Founded Navigation Structures"
- ETL 1110-2-532 "Reliability Assessment of Navigation Structures"

# New Engineering Reliability Guidance

## Existing Geotechnical Guidance

Currently, there are two active geotechnical reliability documents although the main sections of these will be rolled into the new EC document in order to have a single source

Currently active geotechnical guidance

- ETL 1110-2-547 covers basic reliability applications for geotech engineering
- ETL 1110-2-561 covers seepage and slope stability reliability applications for embankment dams

New EC will cover recent developments associated with potential time dependent aspects of seepage & piping reliability

Expired geotechnical guidance

- ETL 1110-2-556 covered reliability assessment of levees

# New Engineering Reliability Guidance

## Existing Mechanical/Electrical Guidance

Currently, there is one active document related to mechanical and electrical reliability assessments for hydropower projects (ETL 1110-2-550) -- uses survivorship curves

Recently mechanical/electrical guidance (expired June 2006)

- ETL 1110-2-560 covers basic reliability applications for mechanical and electrical aspects of navigation locks and dams
- Overall, the methodology is appropriate, but there are some major changes than need to be made (minor components and failure rate problems)
- Application using these methods had to be used with extreme caution

Current plan for mechanical/electrical guidance

- USACE team of mech/elec engineers, along with reliability experts, will develop applicable failure rates for navigation lock and dam uses
- Only critical components will be considered in the analysis
- Goal is to have updated failure rates and improved method by end FY06
- These improvements will be rolled into the new EC document

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# New Engineering Reliability Guidance

## General Information

- Three Year Plan to Develop Infrastructure Reliability Guidance Engineering Circular (EC)
  - Initial funds received in FY04 to establish team, set general schedule, outline
  - Guidance will cover all major engineering disciplines (structural, geotechnical, mechanical, electrical, as well as basic economic aspects)
  - Integration with economics and plan formulation also included
- Technical Team Spread throughout USACE
- New Guidance Needs to be Incorporated in Major Rehab Evaluation Guidance with Respect to Engineering Requirements as well as Other Uses (Systems Studies, Evaluation of Existing Deteriorated Structures)

# New Engineering Reliability Guidance

## March 2005 Progress Review Meeting w/ HQ

FY05 Funds Received in February Limiting Much Progress During First ½ of FY

Progress Review Meeting with HQ in March 2005

Refined Outline as Per April 2004 Meeting Used as Guide

Major Portions of Following Main Volume Completed:

- Chapter 1 – Introduction and Background
- Chapter 3 – Engineering Reliability Guidelines
- Chapter 5 – Engineering and Economic Integration

Refocus Document to be More Business Line/Project Oriented

- Previous version from FY04 was separated by discipline

# New Engineering Reliability Guidance

## Major Changes Out of March 2005 Meeting

Personnel at Meeting Approved Idea with Following Taskers from that Meeting

- Create New Technical Appendices on Project/Business Line Basis
- Determine Appropriate POC's to Lead These Appendices
- Revise Main Volume Outline to Pull in General Discussions Regarding Reliability Analysis for Select Disciplines

New Technical Appendices and Technical Leads

- Navigation Appendix (David Schaaf, Louisville)
- Flood Protection Appendix (Robert Patev, New England)
- Hydropower Appendix – (James Nolan, former USACE from HDC)
- Coastal and Port Structures – (Dr. Jeff Melby, ERDC-WES)

Technical Appendices to Contain Practical Examples/Case Studies

Refine Main Volume Sections to Includes General Discipline Guidance

# New Engineering Reliability Guidance

## Current Status of Document

**Outline for Main Volume**

1. Introduction & Background (purpose, history, on-going initiatives)
2. Engineering Reliability Guidelines (load cases, criteria analysis)
3. Methodologies for Reliability Analysis (available methods, model set-up)
4. Expert Elicitation Methodology (general overview, when to use)
5. Systems Reliability Applications (component redundancy, parallel, series)
6. Engineering & Economic Integration (event trees, base condition)
7. Risk & Reliability for USACE Studies (major rehab, systems studies)
8. Integration with USACE Dam Safety Program (portfolio risk analysis)
9. Risk and Reliability Issues for Navigation Locks & Dams
10. Risk and Reliability Issues for Flood Control Projects
11. Risk and Reliability Issues for Hydropower Projects
12. Risk and Reliability Issues for Coastal/Port Structures
13. Guidelines for Report Writing
14. References

# New Engineering Reliability Guidance

## Current Status of Document

**Outline for Navigation Lock and Dam Appendix**

1. Land Lock Wall Stability Reliability Analysis Example (ORMSS)
2. Approach Wall Stability Reliability Analysis Example (ORMSS)
3. Simplified Hydraulic Steel Structure Reliability Example (GLSLS)
4. HF Miter Gate Reliability Analysis Example (Markland Major Rehab)
5. Mass Concrete Deterioration Reliability Example (Chickamauga)
6. Concrete Stilling Basin Scour Example (J.T. Myers Major Rehab)
7. Miter Gate Machinery Reliability Analysis Example (ORMSS)
8. Lock Electrical Systems Reliability Analysis Example (ORMSS)

**Appendix Examples Have Complete Process of Model Development Including:**

Selection of Modeling Features (Random Variables, Constants, Etc…)
Development of Applicable Limit State
Reliability Model Output and Interpretation
Development of Consequence Event Tree
Economic Analysis
Summary of Results

# New Engineering Reliability Guidance

## Current Status of Document

**Outline for Flood Control Appendix**

1. **Embankments and Levee Examples**
   - a. **Hodges Village Dam Major Rehab Study**
   - b. **Wolf Creek Dam Major Rehab Study**
2. **Outlet Works for Flood Control Projects**
   - a. **Corrosion/Fatigue of Gates**
   - b. **Performance of Conduits**
3. **Concrete Structures for Flood Control Projects**
   - a. **Erosion of Spillways**
   - b. **Alkali Aggregate Reaction**
4. **M/E Equipment for Flood Control Projects**
   - a. **Reliability Block Diagrams (Wolf Creek)**
   - b. **Fault Tree Analysis (Wolf Creek)**

# New Engineering Reliability Guidance

## Current Status

- During FY06, Main Personnel Developing Document Redirected to Katrina Work
  - Others working on guidance heavily involved with Dam Safety SPRA
- Originally Scheduled for Draft EC by 30 Sep 06
- May Have Slight Extension into FY07 to Wrap Up Draft Document
- Handing Off to A/E or Others Not the Best Option for Completing a Comprehensive EC that Meets Intended Need

# New USACE DX for Risk and Reliability

# Reasons to Establish DX for Risk & Reliability

- Requested by Jerry Barnes at 2005 USACE Infrastructure Conference in St. Louis
- Risk and Reliability Becoming Cornerstone Analysis Tool for Developing Systematic Investment Plans
  - Dam Safety Portfolio Risk Assessment (PRA)
  - Navigation River Systems Studies (ORMSS, GLSLS)
  - Major Rehabilitation Program (Increasing with Aging Infrastructure)
  - Asset Management and Metrics for O/M Budgeting
- Problems Across USACE with Appropriate R&R Applications
  - No Experienced Group to Lead and Review Risk-Based Studies
  - Districts Applying Methodology Inappropriately and Inconsistently
  - DX Serve as USACE Review Team for Engineering R & R Applications
- Need Engineering Group to Coordinate On-Going R&D Efforts with IWR and ERDC
- Integrated with Planning CX for Inland Navigation in Huntington District
- Training and Building USACE Expertise in Risk and Reliability
- Risk and Reliability Work for Others
  - Panama Canal Authority (Full Scale Risk Assessment for ACP)
  - Canadian Government (Transport Canada Requests USACE Expertise)

# Responsibilities of R&R DX

## Dam Safety Program

- ✓ PRA Tool Methodology & Process Development
- ✓ Train Field Engineers/Economists on Use of PRA Tool
- ✓ Future Center for Review of PRA Analysis and DSA Studies
- ✓ Future R&D Efforts for Modification of PRA Process

## Major Rehabilitation Program

- ✓ Train Field Engineers/Economists on Analysis Techniques/Requirements
- ✓ Center of Review for Future Major Rehab Studies

## General HQUSACE Directed Efforts

- ✓ Engineering Risk and Reliability Guidance
- ✓ Integrating R & R into USACE Asset Management Program
- ✓ Lead R & D for Model Development through IWR and ERDC

## International Work for Others

- ✓ Great Lakes and St. Lawrence Seaway Study
- ✓ Panama Canal Authority Infrastructure Risk and Reliability Study

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# Thank You

## Questions???

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